

SOUTHERN COASTAL SANTA BARBARA CREEKS BIOASSESSMENT PROGRAM

2009 REPORT AND UPDATED INDEX OF BIOLOGICAL INTEGRITY

JANUARY 2010

Prepared for:

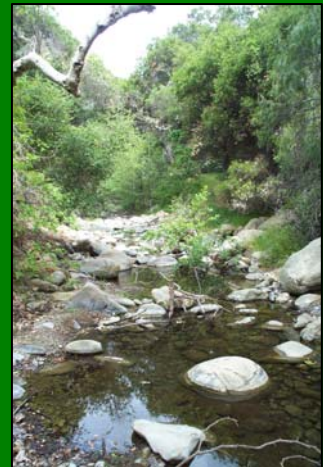
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Executive Summary

Introduction

This report summarizes the results of the 2009 Southern Coastal Santa Barbara Creeks Bioassessment Program, an effort funded by the City of Santa Barbara and County of Santa Barbara. Ecology Consultants, Inc. (Ecology) prepared the report, and serves as the City and County's consultant for the Program. The purpose of the Program is to assess and monitor the biological integrity of creeks in the study area as they respond through time to natural and human influences. The Program involves annual collection and analysis of benthic macroinvertebrate (BMI) samples and other pertinent physiochemical and biological data in study creek reaches using U.S. Environmental Protection Agency (USEPA) endorsed rapid bioassessment techniques. BMI samples are analyzed in the laboratory to determine BMI abundance, composition, and diversity.

This report presents data collected in 2009 and previous years, and an updated Index of Biotic Integrity (IBI) for streams in the study area. The updated IBI was developed by Ecology using the 10 years of Program data from 2000 to 2009. The previous IBI was developed in 2003 using four years of Program data (2000 to 2003). The IBI is a system that yields a numeric score and classifies the biological integrity of a given stream as Very Poor, Poor, Fair, Good, or Excellent based on the BMI community present in the stream, as determined by completing a bioassessment survey and associated laboratory and analytical work. Several "core BMI metrics" are calculated and used to determine the IBI score. Ideally, core metrics are highly sensitive to human disturbance, and collectively represent different aspects of BMI community structure including diversity, community composition, and trophic group representation. By condensing complex biological data into an easily understood score and classification of biological integrity, the IBI serves as an effective tool for the City and County in monitoring the overall condition of local creeks, and taking appropriate watershed management actions.

Study Area

The study area encompasses approximately 60 km of the southern Santa Barbara County coast from the Rincon Creek watershed at the Santa Barbara/Ventura County line west to Gaviota Creek. There are approximately 40 1st to 5th order coastal streams along this stretch of coast, all of which drain the southern face of the Santa Ynez Mountains. A total of 49 stream study reaches in 20 watersheds have been surveyed on one or more occasions during the springs and summers from 2000 to 2009. 24 stream study reaches were surveyed this year.

Methods

Physiochemical and biological data for the study reaches was gathered through a combination of methods including field surveys, laboratory analyses, spatial data analyses using geographic information system software, and review of United States Geological Survey (USGS) 7.5-minute quadrangle maps and recent aerial photographs. Numerous physiochemical and BMI parameters were calculated for each study reach based on the data collected.

Study reaches were separated into three groups based on physiochemical parameters including watershed land use patterns and physical habitat assessment score:

- REF (undisturbed to lightly disturbed by human development)
- MOD DIST (moderately disturbed by human development)
- HIGH DIST (highly disturbed by human development)

Statistical tests including analysis of variance (ANOVA) and linear regression were used to evaluate the data, including for differences in BMI metrics between the three study reach groups described above. The updated IBI was developed based on the statistical analyses.

Results and Discussion

Using the results of the statistical analyses, seven core BMI metrics were selected for inclusion in the updated IBI:

- # of insect families
- # of EPT families
- % EPT minus Baetidae
- % PT
- Biotic index score
- % sensitive BMIs
- % predators + shredders

The core metrics were among the most sensitive to human disturbance among all the metrics tested, either increasing or decreasing from HIGH DIST to MOD DIST to REF groups. None had significant natural relationships with the group of physiochemical parameters among the REF sites. Collectively, the core metrics are diversified in that they represent different aspects of BMI community structure including diversity, disturbance sensitivity, and trophic structure. Scoring ranges for the core metrics and classifications of biotic integrity are provided in the report.

IBI scores were calculated for the study reaches, and classifications of biological integrity were compared to the *a priori* (i.e., prior to analyses of BMI metrics) designations as REF, MOD DIST, or HIGH DIST. The accuracy of the IBI in classifying biological integrity was determined to two and three classes of biological integrity using a Validation Set of 37 study reaches that were not used to develop the IBI. The IBI was accurate 81 percent of the time to two classes and 100 percent of the time to three classes of biological integrity for the Validation Set. These results indicate that the IBI is mostly reliable in classifying the biological integrity of streams in the study area. ANOVA and regression analyses results indicate highly significant relationships between IBI score and human disturbance metrics representing watershed land use patterns and localized physical habitat conditions.

Recommendations

The updated IBI is based on a set of streams that collectively represent a wide range of natural physiochemical variability and levels of human disturbance. In addition, significant fluctuations in rainfall and peak stream flows from year to year and their effects on the BMI communities of

study area streams have been documented over the past 10 years. This has allowed for the development of an IBI that serves as a very reliable tool for classifying the biological integrity of streams in the study area, monitoring their condition through time, and identifying any changes that may occur in the future from increased development, habitat restoration projects, and even long term climatic changes (e.g., global warming).

There are ways in which the collective data set could be diversified, for example by including some of the streams in the study area that have not yet been surveyed, and expanding the study area further west and north to the Hollister and Bixby Ranch areas, Point Conception, Santa Ynez River watershed, etc. The IBI should be updated every 5 to 10 years to account for the greater range of conditions observed.

The updated IBI represents an excellent tool for assessing and monitoring the biological condition of freshwater streams in the study area. However, there is no equivalent tool for estuarine waters in the study area, which could be assessed using similar bioassessment methodology as used in this Program. IBIs have been produced for estuarine waters in many regions, and with adequate data one could be produced in the study area as well. Given the ecological importance of estuarine waters, and their importance as they relate to commercial and recreational uses and the local economy, the City and County should consider implementing an estuarine bioassessment program if funding allows.

Acknowledgement

Special thanks go to Scott Cooper, Professor of Aquatic Biology at the University of California, Santa Barbara for reviewing this report and the Updated IBI, and for his invaluable input throughout the 10 years of this bioassessment program.

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I. Introduction

This report summarizes the results of the 2009 Southern Coastal Santa Barbara Creeks Bioassessment Program, an effort funded by the City of Santa Barbara and County of Santa Barbara. 2009 is the 10th year of the Program, which began in 2000. Ecology Consultants, Inc. (Ecology) prepared the report, and serves as the City and County's consultant for the Program. The purpose of the Program is to assess and monitor the "biological integrity" of southern coastal Santa Barbara County creeks as they respond through time to natural and human influences. Karr and Dudley (1981) defined biological integrity as "the ability to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region." (Miller et al., 1988). "Bioassessment" is the science of assessing the biological integrity of aquatic ecosystems by evaluating the biological assemblages (e.g., benthic macroinvertebrates, fish, amphibians, diatoms, etc.) that inhabit them. Because different species or groups of species (i.e., genera, families, orders, etc.) have varying habitat requirements and abilities to withstand water pollution and other forms of habitat degradation, the presence, abundance, or absence of particular species or groups of species provides information regarding the biological integrity of a particular water body. In addition, measurements of biological community structure relating to overall abundance, diversity, and trophic structure have proven to be reliable indicators of biological integrity in water bodies (Rosenberg and Resh, 1993, Barbour et al., 1999).

The Program involves annual collection and analysis of benthic macroinvertebrate (BMI) samples and other pertinent physiochemical and biological data in study creek reaches using U.S. Environmental Protection Agency (USEPA) endorsed rapid bioassessment techniques. BMI samples are analyzed in the laboratory to determine BMI abundance and composition. This report presents data collected in 2009 and previous years.

This report also presents an updated Index of Biotic Integrity (IBI) for streams in the study area, which was developed using data from a wide range of study reaches surveyed from 2000 to 2009. The IBI provides a numeric score and classification of biological integrity of a given stream as Very Poor, Poor, Fair, Good, or Excellent. Determination of the IBI score of a given study reach starts with collection of BMI samples during a bioassessment survey. Laboratory and analytical work are completed to determine BMI abundance and taxonomic composition. The BMI data is used to calculate several "core metrics", which are the basis of the IBI scores and classifications. Ideally, core metrics are highly sensitive to human disturbance, and collectively represent different aspects of BMI community structure including diversity, community composition, and trophic group representation. By condensing complex biological data into an easily understood score and classification of biological integrity, the IBI serves as an effective tool for the City and County in monitoring the overall condition of local creeks, and making appropriate creek and water quality management decisions.

The IBI was updated to use the considerable data set now available, which collectively represents wide variability in physiochemical conditions, human impacts, and year to year fluctuations in rainfall and stream flow patterns. The current data includes surveys conducted during several drought years and wetter years, including one of the wettest rainfall years on record (2005). Because year to year variability in rainfall and stream flow has been linked to considerable differences in BMI community structure, the updated IBI is more representative of

the full range of the BMI community compared to its predecessor, which was produced in 2003 using the first four years of data (i.e., 2000 to 2003). More discussion of the IBI and its development is provided in III. Methods.

II. Study Area



The study area encompasses approximately 60 km of the southern Santa Barbara County coast from the Rincon Creek watershed at the Santa Barbara/Ventura County line west to Gaviota Creek (see Figure 1). There are approximately 40 1st to 5th order coastal streams along this stretch of coast, all of which drain the southern face of the Santa Ynez Mountains. A total of 47 stream study reaches in 20 watersheds have been surveyed on one or more occasions during the springs and summers from 2000 to 2009. Table 1 lists the study reaches and their locations.

Table 1: Study Reaches

Study Reach	Location
RIN0	Rincon Creek just upstream of Rincon Rd. crossing
RIN1	Rincon Creek, just upstream of Highway 150 crossing at Gobernador Cyn Rd.
C1	Carpinteria Creek, 0.25 mi. downstream of Carpinteria Ave.
C2	Carpinteria Creek, approx. 0.25 mi. upstream of U.S. 101
C3	Gobernador Creek, approx. 0.25 mi. upstream of County detention basin
F1	Franklin Creek just upstream of entrance into Carpinteria Salt Marsh
SM1	Santa Monica Creek just upstream of entrance into Carpinteria Salt Marsh
MONT1	Montecito Creek at Val Verde prop., below Hot Springs/Cold Springs confluence
MONT2	Montecito Creek just upstream of Hot Springs/Olive Mill Rd.
SY1	Sycamore Creek just below Mason St. bridge
SY2	Sycamore Creek just below Highway 192 crossing and Coyote/Sycamore confluence
SY3	Sycamore Creek 300m below Highway 192 crossing and Coyote/Sycamore confluence
M1	Mission Creek at De la Guerra St.
M2	Old Mission Creek at Bohnet Park
M3	Mission Creek at upstream end of Rocky Nook Park
M4	Rattlesnake Creek, approx. 0.5 mi. upstream of Las Canovas Rd. crossing
M6	Mission Creek, at three falls above Jesuita Trail crossing
M7	Old Mission Creek just downstream of Anapamu St.
AB1	Arroyo Burro at upstream end of Alan Rd.
AB2	Arroyo Burro just downstream of Torino Rd.
AB3	San Roque Creek, 0.25 mi. upstream of Foothill Rd.
AB4	San Roque Creek just upstream of the confluence with Arroyo Burro
AB5	Mesa Creek at entrance to Arroyo Burro estuary
AB6	Arroyo Burro just downstream of U.S. 101
AT1	Atascadero Creek near Patterson Rd.
AT2	Atascadero Creek just downstream of Cieneguitas Creek confluence

Table 1: Study Reaches

SA1	San Antonio Creek, approx. 0.5 mi. upstream of Tucker's Grove Park
SA2	San Antonio Creek, approx. 0.25 mi. upstream of Highway 154
MY1	Maria Ygnacio Creek, approx. 0.25 mi. below San Marcos Rd. crossing
MY2	Maria Ygnacio Creek, approx. 0.25 mi. upstream of FC detention basin
MY3	Maria Ygnacio Creek, approx. 0.25 mi. upstream of Highway 154
SJ1	San Jose Creek, approx. 0.25 mile downstream of U.S. 101
SJ2	San Jose Creek, approx. 0.25 mile upstream of Patterson Rd. crossing
SJ3	San Jose Creek at San Marcos Trout Club
T1	Tecolote Creek, approx. 50 meters upstream of Vereda del Padre
T2	Tecolote Creek, adjacent to Vereda Nueva
T3	Tecolote Creek, 100 m downstream from Vereda Parque access
DP1	Dos Pueblos Creek, approx. 50 meters downstream of U.S. 101
EC1	El Capitan Creek in State Park, approx. 100 meters upstream of mouth
R1	Refugio Creek, approx. 1.5 mi. upstream of U.S. 101
R2	Refugio Creek, approx. 0.25 mi. downstream of Circle Barbee Ranch
AH1	Arroyo Hondo, approx. 1 mi. upstream of U.S. 101.
AH2	Arroyo Hondo, approx. 2 mi. upstream of U.S. 101.
SO1	San Onofre Creek, just below U.S. 101 culvert
SO2	San Onofre Creek, approx. 1 mi. upstream of U.S. 101
GAV1	Gaviota Creek at State Beach/Park, just below access rd./US 101 junction
GAV2	Gaviota Creek, 200 meters downstream of Las Canovas Creek confluence

The study reaches range from narrow mountain tributaries to wider lowland streams, and from relatively pristine to highly disturbed. Common human impacts observed in study streams include: (1) altered hydrology and geomorphology due to water diversions, land development, and flood control projects; (2) sedimentation of pool and riffle substrata due to increased deposition of fine sediments from actively eroding agricultural fields and creek banks; (3) degraded water quality due to inputs of fertilizers, pesticides, petroleum hydrocarbons, heavy metals, and other pollutants; (4) elevated stream temperatures due to drainage from impervious surfaces and the removal of riparian vegetation; (5) habitat fragmentation due to the construction of in-stream barriers such as dams, road crossings, bridges, and culverts; (6) introductions of invasive, non-native plants and animals; and (7) disturbances to vegetation and/or wildlife associated with trampling, noise, lighting, air pollution, and predation by domestic pets.

FIGURE 1: STUDY AREA



III. Methods

Physiochemical and biological data for the study reaches was gathered through a combination of methods including field surveys, laboratory analyses, spatial data analyses using geographic information system (GIS) software, and review of United States Geological Survey (USGS) 7.5-minute quadrangle maps and recent aerial photographs. Numerous physiochemical and biological parameters were calculated for each study reach based on the data collected. After the data set was finalized, statistical tests including analysis of variance (ANOVA) were used to evaluate the data, and the IBI was developed. Further discussion of methods is provided below.

A. Field Surveys

As in previous years of the Program, field surveys were conducted in the spring during base stream flow conditions (i.e., low flows). The sampling was conducted in early May of 2009 by Ecology, City of Santa Barbara, and County of Santa Barbara staff. Sampling in the spring during base flow conditions provides consistency in the sampling from year to year, as the local stream biota is known to undergo seasonal succession (Cooper et al., 1986). The following was completed during each field survey:

- General observations were recorded on a standardized field data sheet, including location, date, time, weather, stream flow conditions, water clarity, and human impacts.
- A 100-meter study reach was delineated along the stream. Stream habitat units (i.e., riffles, runs, pools, etc.) within the study reach were mapped and quantified as a percentage of the total reach length.
- GPS coordinates were determined at the downstream end of each study reach using a Garmin E-Trex Venture handheld GPS unit.
- Stream widths (wetted perimeter, channel bottom, and bank full) were measured at three transects in the study reach. Wetted perimeter width is defined as the cross-sectional distance of streambed that is inundated with surface water. Channel bottom width is defined as the cross-sectional distance between the bottoms of the stream banks. Bank full width is defined as the distance from the ordinary high water mark from one stream bank to the other, as evidenced by visible signs of stream flow such as water marks, stream-carried deposits of sediments and debris, and scour features.
- Riparian canopy cover was estimated in the center of the stream channel at the three transects using a spherical densitometer.
- Plant and wildlife species observed in the creek and riparian zone were noted.
- Water temperature, specific conductance, pH, and dissolved oxygen concentration were measured in the field using YSI and Oakton handheld meters. Two measurements of each parameter were made, one in a riffle and the other in a pool, and the two values were averaged.
- BMI samples were collected using a standardized method based on the "multi-habitat" approach described in the USEPA's *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers* (Barbour et al., 1999). Three samples were collected per study reach: one

sample from the downstream third of the reach, one from the middle third, and one from the upstream third. Each sample represents approximately one square meter of stream bottom, collected from 10 individual, 0.1-square meter locations (approximately 30 centimeters square). The 10 locations that constituted each sample were selected based on the relative area each stream habitat (i.e., riffles, pools, falls, etc.) covered in the section of stream sampled. For example, if a given stream reach contained approximately 50 percent riffles and 50 percent pools, five locations in riffles and five in pools were selected and sampled. Samples were collected using a D-frame net with 500 μm mesh. In locations with flowing water (e.g., riffles and runs), the net was held upright against the stream bottom, and substrata immediately upstream within the 0.1-square meter area was scraped and stirred up for approximately 15 seconds using feet and hands. Dislodged BMIs and stream bottom materials were carried into the net by the stream current. In areas with little or no current (e.g., pools), stream bottom material was stirred up by foot, followed by a quick sweep of the net through the water column to capture dislodged BMIs. This was repeated three times in each pool sampling location.

- After each BMI sample was collected, it was rinsed with water in a 500 μm sieve to wash out fine sediments, transferred to a plastic container, and preserved in 70 percent ethanol.
- A semi-quantitative stream habitat assessment was conducted using the protocol provided in the USEPA's *Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers*. Per this protocol, habitat components were visually assessed and scored, including stream substrate/cover, sediment embeddedness, stream velocity/depth regime, sediment deposition, channel flow status, human alteration, channel sinuosity, habitat complexity/variability, bank stability, vegetative protection, and width and composition of riparian vegetation. Each study reach was assigned a total score of between zero and 200 based on the sum of scores assigned to each habitat component. Criteria from the USEPA protocol were used to guide the scoring.
- Quality control measures were incorporated into the field surveys to insure accurate and consistent data gathering. Water monitoring equipment was calibrated regularly. Field crew members were trained to properly operate equipment, take measurements, collect BMI samples, and conduct stream habitat assessments. Stream habitat assessment scoring was done as a group by the field crew.

B. Laboratory Analyses

BMI samples were processed in the laboratory to determine BMI community composition (i.e., taxa present and relative abundance) and overall density. Each BMI sample was strained through a 500- μm mesh sieve and washed with water to remove ethanol and fine sediments. The sample was placed in a plastic tray marked with equally-sized squares in a grid pattern. The entire sample was spread out evenly across the squares. Squares of material were randomly selected, and sorted one at a time under a dissecting microscope (7X to 50X magnification) until a specified number of BMIs were located and picked out. The proportion of the sample sorted was noted. 110 specimens were picked out from each sample (i.e., three samples, 330 BMIs per study reach). 100 of the 110 BMIs picked from each sample (300 total per study reach) were randomly selected for identification. BMIs were identified using standard taxonomic keys. Insect taxa were identified to the family level. Non-insect taxa (e.g., oligochaetes, crustaceans, etc.) were identified to order or class. After processing and

identification, sorted BMIs and sample remnants were bottled separately in 70 percent ethanol for storage.

Quality control measures were incorporated into the laboratory analysis to ensure random selection and accurate enumeration and identification of BMIs. BMI sample processing methods were clearly established and strictly followed.

C. GIS Analyses

GIS Arcview software was used to calculate upstream watershed area and watershed land use coverages for each study reach. Watershed area was calculated based on watershed boundaries generated by the GIS with a 30 meter digital elevation model using hydrologic processing tools in Arcview GIS. Watershed land use coverages for each study reach were calculated by superimposing watershed boundaries over a digital land cover GIS layer for the region. The land cover layer was produced the California Department of Forestry and Fire Protection's (CDF) Fire and Resource Assessment Program (FRAP). The land cover layer is titled LCMMP Vegetation Data, 1994 to 1997. The CDF land use map for the region showed coverage by the following eight land use categories: urban, agriculture, herbaceous, hardwood, shrub, conifer, water, and barren/other. Recent aerial photographs (i.e., 2008 and 2009) of the region available on Google Earth were reviewed to check the accuracy of the GIS land use layer. The GIS and aerial photograph land use maps were in close agreement, and only minor adjustments to the GIS-based calculations were necessary.

The parameter "percent watershed disturbed" was calculated for each study reach by using the following equation:

Percent watershed disturbed = percent urban + percent agriculture + 0.5(percent herbaceous)

Herbaceous areas were counted as partially (i.e., half) disturbed to reflect that much of the herbaceous lands in this region are used for livestock grazing or are previously cleared land.

D. Review of Topographic Maps

USGS 7.5 minute quadrangle topographic maps (1:24,000 scale) for the study area were reviewed to determine stream order, elevation, and gradient for each study reach. Gradient was determined by dividing the elevation change between topographic contours immediately upstream and downstream of the study reach by the stream length between the contours. Stream length was determined by tracing a map wheel over the stream path.

E. Study Reach Grouping

The study reaches were placed into three different groups based on their perceived level of human disturbance. These disturbance groups were assigned to study reaches "a priori" (i.e., before the analyses of biological data) based on physical habitat assessment scores and GIS data on watershed land uses. The following criteria were used to group the study reaches:

REF = Reference stream reaches are minimally disturbed by human activities. Habitat assessment score was 150 out of 200 or greater, and five percent or less of the upstream watershed was disturbed.

MOD DIST = Stream reaches that are lightly to moderately disturbed by human activities. Habitat assessment score was between 120 and 149. This category also includes

stream reaches with a habitat assessment score of 150 or greater, but with greater than five percent of the upstream watershed disturbed.

HIGH DIST= Stream reaches that are heavily disturbed by human activities including agricultural and urban/suburban land uses. Habitat assessment score was less than 120.

F. Calculation of Physiochemical Parameters and BMI Metrics

Numerous physiochemical parameters and BMI metrics were calculated for each study reach using the data collected. Table 2 lists each parameter calculated for the study reaches and the method of calculation (e.g., lab, field, etc.).

Table 2 Physiochemical Parameters and BMI Metrics Calculated for Each Study Reach		
Parameters	Units of Measurement	Method of Calculation
PHYSICAL PARAMETERS		
Stream order	None	USGS Quad Maps
Elevation	Feet (ft.)	USGS Quad Maps
Stream gradient	None	USGS Quad Maps
Watershed area	Acres	GIS
Percent of watershed area disturbed	None	GIS
Wet stream width	Ft.	Field
Habitat assessment score	None	Field
Percent riparian canopy cover	None	Field
WATER CHEMISTRY PARAMETERS		
Stream temperature	Degrees Celsius (°C)	Field
Ph	None	Field
Dissolved oxygen concentration	Milligrams per liter (mg/l)	Field
Conductivity	Microsiemens (µS)	Field
Specific conductance (corrected to 25° Celsius)	µS	Field
BIOLOGICAL PARAMETERS		
BMI density	# per sq. meter (#/m ²)	Field/lab
# of insect families	None	Field/lab
# of Ephemeroptera/Plecoptera/Tricoptera (EPT) families	None	Field/lab
Percent EPT	None	Field/lab
Percent EPT minus Baetidae	None	Field/lab
Percent Plecoptera/Tricoptera (PT)	None	Field/lab
Percent Coeloptera	None	Field/lab
Biotic index score	None	Field/lab
Percent sensitive BMIs	None	Field/lab
Percent tolerant BMIs	None	Field/lab
Percent non-insect BMIs	None	Field/lab
Percent non-insects + Diptera	None	Field/lab
Percent non-insects + Chironomidae	None	Field/lab
Percent collector-gatherers	None	Field/lab
Percent scrapers	None	Field/lab
Percent shredders	None	Field/lab
Percent collector-filterers	None	Field/lab
Percent predators	None	Field/lab
Percent predators + shredders	None	Field/lab

Table 2
Physiochemical Parameters and BMI Metrics Calculated for Each Study Reach

Percent scrapers + shredders	None	Field/lab
Percent scrapers + shredders + predators	None	Field/lab
Percent collector-gatherers + scrapers + shredders	None	Field/lab
Percent collector-gatherers + collector-filterers	None	Field/lab
Percent collector-gatherers + predators	None	Field/lab

Numerous BMI metrics were calculated for each study reach to reflect different aspects of community structure, including overall BMI density, richness, composition (i.e., taxa present), the relative and absolute abundances of component taxa or groups, trophic group representation, and sensitivity to human disturbance. BMI metrics for each study reach were calculated by combining the data from the three samples.

BMI density (number of individuals per m²) was calculated by dividing the number of specimens picked out of the sample by the sub sampled area. Richness parameters were determined by counting the number of specified taxa identified in each sample. Functional feeding group parameters (e.g., percent collector-gatherers, % scrapers, etc.) were determined using functional feeding group designations for individual taxa provided in Merritt and Cummins (1996).

Biotic index scores, percent sensitive BMIs, and percent tolerant BMIs were calculated using disturbance tolerance values for individual BMI taxa provided in *List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort* (California Department of Fish and Game, 2002). This document assigns tolerance values to individual taxa ranging from 0 to 10 based on their perceived ability to withstand human disturbance. A tolerance value of 0 indicates that a particular BMI is extremely intolerant of human disturbance, with increasing scores indicating greater tolerance to human disturbance. Composite biotic index scores were calculated by adding the tolerance values for each BMI in the sample, and dividing by the total number of individuals. Percent sensitive BMIs was calculated by adding the number of BMIs in the sample with a tolerance value of 2 or less, dividing by the total number of individuals in the sample, and multiplying by 100. Percent tolerant BMIs was calculated by adding the number of BMIs in the sample with a tolerance value of 8 or greater, dividing by the total number of individuals in the sample, and multiplying by 100. Tolerance values were available for more than 95 percent of the taxa collected. BMIs without tolerance values were excluded from the calculations of biotic index scores, percent sensitive BMIs, and percent tolerant BMI taxa.

G. Development of New Tolerance Values for Study Area BMI Taxa, and New Biotic Index Score, Percent Sensitive BMIs, and Percent Tolerant BMIs Metrics

In completing 10 years of the Program, it has become apparent that tolerance values assigned to some of the individual BMI taxa in the *List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort* do not agree with the occurrences observed in the study area. As an example, the mayfly family Caenidae is assigned a relatively high tolerance value of 7, yet it is rarely observed in significant numbers in highly disturbed creeks in the study area, and is often observed in significant numbers in minimally and moderately disturbed creeks. In an

attempt to refine the accuracy of the biotic index score, tolerance values specific to the study area were developed using the data from all study reaches surveyed in four or more years. This included data from 153 surveys.

Tolerance values were determined for all BMI taxa having a mean abundance of at least one individual per study reach in at least one of the study reach groups (REF, MOD DIST, and/or HIGH DIST). For BMI taxa not meeting these criteria, tolerance values from *List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort* were retained.

In order to evaluate their sensitivity to human disturbance, all qualifying BMI taxa were evaluated for differences between the REF, MOD DIST, and HIGH DIST study reach groups using analysis of variance (ANOVA). The results of the ANOVA tests were used to assign new tolerance values to the qualifying BMI taxa. An ANOVA test compares the means and distributions of a given metric among multiple sampling groups, and indicates the probability that the means for the groups are the same. The probability that the means are the same is expressed as *p*, which is between 0 and 1. The lower the *p*, the lower the probability is that the group means are the same. A *p* of 0.05 or less is generally accepted as indicating a statistically significant difference between group means. Rules for setting the new tolerance values are provided in Figure 2.

The revised tolerance values were used to calculate new versions of the biotic index score, percent sensitive BMIs, and percent tolerant BMIs. The new version of percent sensitive BMIs was further revised to include BMIs with a tolerance value of 3 or less, while the new version of percent tolerant BMIs was revised to include those with a tolerance value of 7 or greater.

H. Development of the Updated IBI

Developing the updated IBI required the completion of several distinct steps, including (1) selection of study reaches to be included in the IBI test group and those to be included in a separate validation group, (2) screening and selection of core metrics, (3) defining scoring ranges for core metrics, (4) defining IBI scoring categories and ranges, and (5) testing the IBI for accuracy in classifying the biological integrity of individual study reaches. These steps are discussed below.

1. Partitioning of Study Reaches into IBI Test Group and Validation Group

The IBI Test Group is composed of study reaches surveyed in four or more years. A total of 153 sampling replicates compose the Test Group, including 34 REF, 40 MOD DIST, and 79 HIGH DIST replicates, respectively. Data from these surveys was used to develop the IBI. All study reaches surveyed less than four times over the 10 year Program were held back, and included in a separate Validation Group composed of 37 surveys from 5 REF, 15 MOD DIST, and 17 HIGH DIST replicates, respectively. Since they were not used to develop the IBI, study stream reaches in the Validation Group can be used to independently test the accuracy of the IBI in correctly scoring and classifying biological integrity.

Figure 2: Tolerance Values Rules**Sensitive
(0-3):**

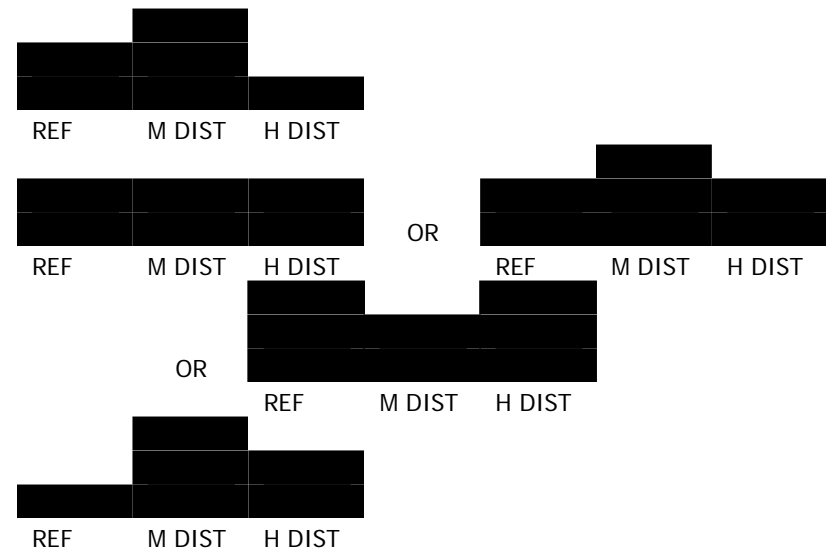
0,1: abundance significantly ($p < 0.05$) highest in REF. MOD DIST and HIGH DIST not sign. different from one another. 0 for greater differences in mean values and p between REF and MOD/HIGH DIST, 1 for lesser differences.

2,3: significant decrease in mean abundance from REF to MOD DIST to HIGH DIST, or from REF and MOD DIST to HIGH DIST. 2 for greater differences in mean values and p, 3 for lesser differences.

**Moderate
(4-6):**

4: mean abundance significantly highest in MOD DIST, mean abundance in REF sign. higher than in HIGH DIST.

5: no significant difference in mean abundance between the three groups. Or mean abundance in MOD DIST sign. higher or lower, and REF and HIGH DIST means not sign. different from each other.



6: mean abundance significantly highest in MOD DIST, mean abundance in REF sign. lower than in HIGH DIST.

**Tolerant
(7-10):**

7,8: significant increase in mean abundance from REF to MOD DIST to HIGH DIST, or from REF to MOD DIST and HIGH DIST. 8 for greater differences in mean values and p, 7 for lesser differences.

9,10: mean abundance significantly highest in HIGH DIST, REF and MOD DIST not significantly different from each other. 10 for greater differences in mean values and p, 9 for lesser differences.



2. Screening of BMI Metrics and Selection of Core Metrics


Sensitivity to Human Disturbance

In order to evaluate their sensitivity to human disturbance, all of the BMI metrics calculated (see Table 2) were evaluated for differences between the REF, MOD DIST, and HIGH DIST study reach groups using ANOVA. BMI metrics that most significantly change (i.e., increase or decrease) with increasing levels of human disturbance (i.e., from the REF to MOD DIST to HIGH DIST groups) have most potential to serve as measures biological integrity, and core metrics in the IBI.

Natural Relationships with Physiochemical Parameters

Multiple regression analyses were used to evaluate natural relationships (i.e., in the absence of human disturbance) between biological metrics and several physiochemical parameters using data REF study reaches group (n=39). It is important to screen potential core metrics on this basis, as significant natural relationships with physiochemical parameters could be difficult to separate from the effects of human disturbance. Such a situation may make a metric an unreliable indicator of biological integrity.

Multiple regression simultaneously evaluates and compares the effects of multiple independent variables (i.e., the physiochemical variables), or “regressors”, on a single response variable (i.e., each biological metric). A best-fit equation is calculated that represents the response variable as a function of the independent variables. The correlation coefficient (r^2) and p-value (p) are calculated in regression analyses, and used to interpret the strength of the relationship between the response variable and the regressors. r^2 is given as a value between 0 and 1, and indicates the how well the equation fits the data. The higher the r^2 , the better the fit of the equation. P indicates the probability that the response variable and regressors are not related as predicted by the best-fit equation, and is given as a value of between 0 and 1. A p of 0.05 or less is generally accepted as indicating a statistically significant relationship between the independent and response variables.

Landscape level, relatively constant physiochemical parameters including elevation, stream gradient, and watershed area were selected for use as regressors in the analyses. Stream temperature has been shown in many studies to have major effects on BMI community structure, and was also used as a regressor. 

Core Metric Selection

Once the above screening analyses were complete, core metrics were selected for inclusion in the IBI. All potential core metrics showed (1) highly significant responses to human disturbance, either increasing or decreasing between REF to MOD DIST to HIGH DIST groups, and (2) less than significant relationships with physiochemical parameters at the REF study reaches. This in theory at least avoids a situation of confusing biological responses to human disturbance with responses to natural physiochemical gradients. Collectively, core metrics were chosen to represent three major aspects of biological community structure: diversity, disturbance tolerance/sensitivity, and trophic composition (i.e., functional feeding groups).

3. Defining Core Metric Scoring Ranges

Scoring ranges of were established for each potential core metric on a dimensionless scale of 0 to 10, 0 indicating the lowest biological integrity, and 10 indicating highest biological integrity.

For metrics that decrease with human disturbance (i.e., highest at REF sites), higher values corresponded with higher scores. For metrics that increase with human disturbance (i.e., highest at HIGH DIST sites), higher values corresponded with lower scores. The distributions of each metric in the REF, MOD DIST, and HIGH DIST groups were used to establish the scoring ranges. Scoring criteria is provided in Table 3.

Table 3: Core Metric Scoring Range Criteria	
Score	Scoring Criteria
10	The 75 th percentile or beyond of the REF group distribution for metrics that are highest in the REF group, or the 25 th percentile or lower of REF group for metrics that are lowest in the REF group
9	The median (50 th percentile) to 75 th percentile of the REF group for metrics that are highest in the REF group, or the 25 th percentile to the median of REF group for metrics that are lowest in the REF group
8	The range between the REF group and MOD DIST group medians is divided and evenly partitioned to provide each scoring range for 6, 7, and 8
7	
6	
5	MOD DIST median is the top of the scoring range for 5
4	The range between the MOD DIST group and HIGH DIST group medians is divided and evenly partitioned to provide each scoring range for 5, 4, 3, and 2
3	
2	
1	The median to 25 th percentile of the HIGH DIST group for metrics that are lowest in the HIGH DIST group, or the median to the 75 th percentile to the median of HIGH DIST group for metrics that are highest in the HIGH DIST group
0	The 25 th percentile or less of the HIGH DIST group distribution for metrics that are lowest in the HIGH DIST group, or the 75 th percentile or higher of the HIGH DIST group for metrics that are highest in the HIGH DIST group

4. Establishment of IBI Classifications of Biological Integrity

An overall IBI score was tabulated for each study reach by summing the respective scores of the core metrics. Based on the distribution of IBI scores for the REF, MOD DIST, and HIGH DIST groups, five categories of biological integrity were established: Excellent, Good, Fair, Poor, and Very Poor. Scoring criteria used to establish the categories is provided in Table 4.

Table 4: IBI Classifications of Biological Integrity and Scoring Criteria

Classification of Biological Integrity	Scoring Range
Excellent	Median of REF group or higher
Good	From REF group median to 2/3 of way down to MOD DIST group median
Fair	Upper end of Fair range is MOD DIST group median to 1/3 of way up to REF group median. Lower end of Fair range is MOD DIST group median to 1/3 of way down to HIGH DIST group median.
Poor	From HIGH DIST group median to 2/3 of way up to MOD DIST group median
Very Poor	Median of HIGH DIST group or less

5. Testing the Accuracy of the IBI

Once the IBI was established, IBI scores were calculated for the study reaches, and classifications of biological integrity were compared to the *a priori* REF, MOD DIST, and HIGH DIST designations. This was done for:

1. the Validation Group only, or study reaches not used to develop the IBI (n=37), and;
2. all study reaches, including those used to develop the IBI (n=190).

The accuracy of the IBI in classifying biological integrity was determined to two and three classes of biological integrity. Table 5 provides criteria for correct classification by the IBI for these two levels of resolution. The percentage of sites properly classified (i.e., accuracy) was calculated for the IBI using these criteria.

Table 5: IBI Accuracy of Classification Criteria

Study Reach Group	Accurate to Two Classes	Accurate to Three Classes
REF	Good to Excellent	Fair to Excellent
MOD DIST	Top half of Poor to bottom half of Good	Poor to Good
HIGH DIST	Very Poor to Poor	Very Poor to Fair

Additional statistical analyses were performed to evaluate the IBI's sensitivity to human disturbance. First, an ANOVA was completed to compare IBI scores for the three study reach groups (REF, MOD DIST, and HIGH DIST). Next, regression analyses were used to evaluate the relationships of IBI score with (1) percent of upstream watershed undisturbed, (2) habitat assessment score, and (3) a composite of percent of upstream watershed undisturbed and habitat assessment score. r^2 and p were calculated for these analyses.

IV. Results and Discussion

A. Data

Table A-1 in Appendix A provides physiochemical and BMI data collected at the study reaches in all years of study, and BMI metrics calculated using the data. New tolerance values determined for individual BMI taxa are also provided, as are previous tolerance values for comparison. Functional feeding groups for individual BMI taxa are provided as well.

B. New Tolerance Values

New tolerance values and sensitivity designations for individual BMI taxa are provided in Table A-1 of Appendix A. New tolerance values were assigned to 46 of 72 BMI taxa. Tolerance values from *List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort* were retained for the remaining 26 taxa, which did not have mean abundance of 1 individual per study reach in at least one of the three disturbance groups. An additional six taxa did not have tolerance values in *List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort*, and did not meet the minimum criteria for establishment of tolerance values in this study.

For 20 of the 46 taxa, new tolerance values were in close agreement with the tolerance values provided in *List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort*. There were notable changes for 26 taxa as follows:

Caenidae	7 (previous tolerance value) to 2 (new tolerance value)
Heptagenidae	4 to 0
Leptohyphidae	4 to 2
Nemouridae	2 to 0
Brachycentridae	1 to 3
Glossostomatidae	0 to 3
Helicopsychidae	3 to 1
Philoematidae	3 to 5
Polycentropodidae	6 to 2
Psychomyiidae	2 to 5
Rhyacophilidae	0 to 2
Elmidae	4 to 0
Halipidae	5 to 9
Psphenidae	4 to 2
Chironomidae	6 to 8
Psychodidae	none available to 5
Stratiomyidae	8 to 3
Tipulidae	3 to 1

Veliidae	none available to 3
Coenagrionidae	9 to 5
Gomphidae	4 to 0
Lestidae	9 to 5
Acari	5 to 3
Gastropoda	8 to 5
Amphipoda	8 to 5
Oligochaeta	5 to 9

Changes in tolerance values and the criteria for sensitive and tolerant BMIs resulted in differences in new biotic index score, percent sensitive BMIs, and percent tolerant BMIs compared to the previous versions of these metrics. This will be discussed in more depth later in the report.

C. Development of the Updated IBI

1. Screening and Selection of Potential Core Metrics

Sensitivity to Human Disturbance

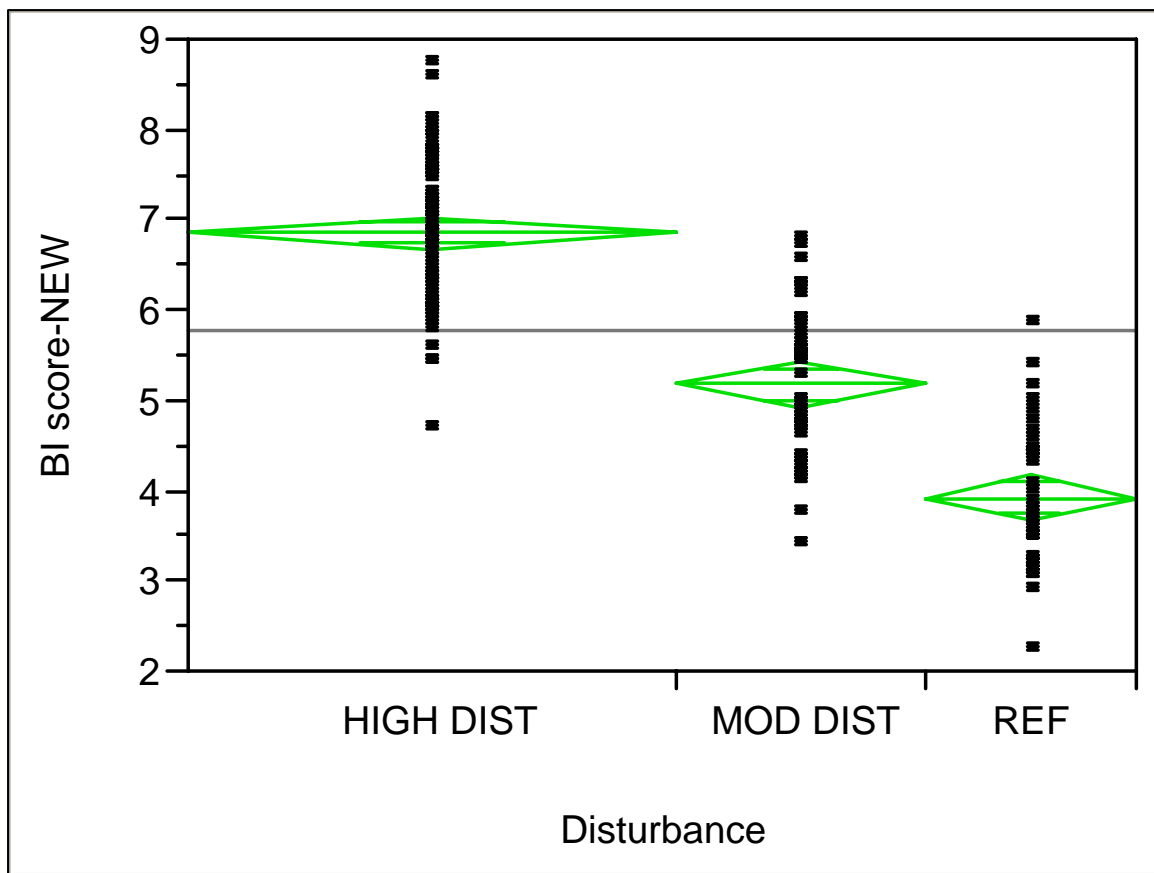
Table A-2 summarizes the results of the ANOVAs conducted to evaluate the sensitivities of the BMI metrics to human disturbance. As an example, Figure 3 illustrates the ANOVA for biotic index score-new, which had a highly significant positive relationship with human disturbance ($p < 0.0001$, $r^2 = 0.71$). Overall, 25 of the 27 BMI metrics evaluated had significant differences between the REF, MOD DIST, and HIGH DIST groups, many with $p < 0.0001$. The only metrics evaluated that did not have significant differences between study reach groups were BMI density and percent scrapers.

The new biotic index score, % sensitive BMIs, and % tolerant BMIs metrics were more responsive to human disturbance compared to the previous versions. The new versions of these metrics had greater differences in means between study reach groups and better p and r^2 compared with the previous versions (see Table A-2). This was particularly the case for % tolerant BMIs and biotic index score.

BMI metrics with the strongest negative responses to human disturbance were # EPT families ($p < 0.0001$, $r^2 = 0.68$), % sensitive BMIs-NEW ($p < 0.0001$, $r^2 = 0.67$), % sensitive BMIs-OLD ($p < 0.0001$, $r^2 = 0.65$), % EPT minus Baetidae ($p < 0.0001$, $r^2 = 0.62$), % PT ($p < 0.0001$, $r^2 = 0.59$), # insect families ($p < 0.0001$, $r^2 = 0.58$), and % shredders + predators ($p < 0.0001$, $r^2 = 0.57$). BMI metrics with the strongest positive responses to human disturbance were biotic index score-NEW ($p < 0.0001$, $r^2 = 0.71$) and % tolerant BMIs-NEW ($p < 0.0001$, $r^2 = 0.56$). These metrics were all considered for further analyses as potential core metrics, except for % sensitive BMIs-OLD, which was slightly less responsive to human disturbance compared to % sensitive BMIs-NEW, and would be redundant with the new metric.

Figure 3: ANOVA Comparison of Biotic Index Score at REF, MOD DIST, and HIGH DIST Reaches

Means and distributions of biotic index score for study reach groups are represented. Top and bottom of diamonds are the 95 percent confidence limits, and the center lines are the means. The lower and upper lines are the 25 percent and 75 percent quantiles. $N=153$, $p<0.0001$, $r^2 = 0.71$. The p value is for the ANOVA where IBI score is the dependent variable and disturbance category is the independent variable.



Natural Relationships with Physiochemical Parameters

Table 6 summarizes the results of the multiple regression analyses conducted to evaluate relationships between the eight potential core metrics and the group of physiochemical regressors at the REF study reaches (n=39). As discussed in Methods, this is an important step in screening the potential core metrics.

Table 6: Summary of Multiple Regression Analyses of Potential Core Metrics vs. Physiochemical Parameters (Elevation, Gradient, Watershed Area, and Stream Temperature) at REF Study Reaches (n=39)		
Potential Core Metric	R²	P
# insect families	0.10	0.39
# EPT families	0.23	0.06
% EPT minus Baetidae	0.03	0.86
% PT	0.12	0.33
Biotic index score	0.15	0.18
% sensitive BMIs-NEW	0.06	0.72
% tolerant BMIs-NEW	0.26	0.03
% predators + shredders	0.09	0.46

The multiple regression for % tolerant BMIs was significantly related to the group of physiochemical regressors ($r^2 = 0.26$, $p=0.03$). Due to this statistically significant relationship, % tolerant BMIs was eliminated from consideration as a core metric. None of the other seven BMI metrics had statistically significant relationships (i.e., $p<0.05$) with the group of physiochemical regressors.

Core Metric Selection

Based on the results presented above, seven core metrics were selected for inclusion in the IBI:

- # of insect families
- # of EPT families
- % EPT minus Baetidae
- % PT
- Biotic index score-NEW
- % sensitive BMIs-NEW
- % predators + shredders

The core metrics were among the most sensitive to human disturbance among all the metrics tested, either increasing or decreasing from HIGH DIST to MOD DIST to REF groups. None had statistically significant natural relationships with the group of physiochemical parameters among the REF sites. Collectively, the core metrics are diversified in that they represent different aspects of community structure including diversity, disturbance sensitivity, and trophic structure.

2. Defining Scoring Categories and Ranges for Core Metrics

Scoring ranges were developed for the core metrics using the criteria presented in Methods. The scoring ranges are provided below in Table 7.

<p align="center">Table 7 Core Metric Scoring Ranges</p>							
Score	# insect families	# EPT families	% EPT-Baetidae	% PT	Biotic index score	% sensitive BMIs	% shredders + predators
10	29+	15	49+	22+	3.21 or less	60+	27+
9	26 to 28	14	37 to 49	15 to 22	3.22 to 3.82	46-59	19 to 26
8	25	12 to 13	32 to 36	12 to 14	3.83 to 4.32	39 to 45	16 to 18
7	24	11	27 to 31	10 to 11	4.33 to 4.81	32 to 38	14 to 15
6	23	10	23 to 26	8 to 9	4.82 to 5.29	26 to 31	12 to 13
5	19 to 22	9	18 to 22	6 to 7	5.30 to 5.68	20 to 25	10 to 11
4	16 to 18	7 to 8	13 to 17	4 to 5	5.69 to 6.07	14 to 19	8 to 9
3	13 to 15	5 to 6	8 to 12	3	6.08 to 6.47	8 to 13	6 to 7
2	10 to 12	3 to 4	2 to 7	2	6.48 to 6.87	2 to 7	4 to 5
1	7 to 10	1 to 2	1	1	6.88 to 7.48	1	2 to 3
0	0 to 6	0 to 1	0	0	7.49+	0	0 to 1

3. Defining IBI Classifications and Scoring Ranges

IBI classifications and scoring ranges were developed using the criteria presented in Methods, and are provided in Table 8.

4. Testing the IBI

Accuracy and Consistency of IBI Scores and Classifications

Table A-3 lists IBI scores and biological integrity classifications for each study reach in the Validation Group (n=37) and the Test Group (n=153). Since the Validation Group study reaches were not used to develop the IBI, they provide a means to independently assess the IBI's accuracy in classifying biological integrity. Using the criteria in Table 5, the IBI was accurate to two classes of biological integrity 81 percent of the time for the Validation Group, and to three classes 100 percent of the time. In theory, if the IBI is incorrect in classifying study reaches to two classes of biological integrity 19 percent of the time, the probability of being incorrect to this level of precision at a given study reach two years in a row would be less than 4 percent. Thus, the IBI appears to be fairly reliable in determining biological integrity to two

classes, which is the desired level of precision. All 37 study reaches in the Validation Set were correctly classified to three classes. Thus, it appears there is little chance for gross inaccuracies in classifying biological integrity with the IBI. Data from study reaches in future years of the Program can be used to further evaluate the IBI's accuracy in classifying biological integrity.

Table 8 Classifications of Biological Integrity and Scoring Ranges	
Category	Scoring Range
Excellent	61 to 70
Good	48 to 60
Fair	31 to 47
Poor	9 to 30
Very Poor	0 to 8

While use of the overall data set (i.e., all 190 study reaches) to validate the IBI's accuracy in classifying biological integrity would be circular (i.e., it includes the data used to develop it), it is useful to explore how the IBI's accuracy differed between study reach disturbance groups (i.e., REF, MOD DIST, and HIGH DIST). For the HIGH DIST study reaches (n=96), the IBI was accurate 94 percent of the time to two classes of biological integrity, and 100 percent of the time to three classes. For the REF study reaches (n=39), accuracy was 87 percent to two classes and 95 percent to three classes of biological integrity. Accuracy was lowest for the MOD DIST study reaches (n=55) at 73 percent to two classes and 93 percent to three classes of biological integrity.

Use of the overall data set also provides information regarding the IBI's accuracy in classifying biological integrity through time. For the most part, IBI scores were fairly consistent from year to year at study reaches sampled in multiple years. The exception to this was 2005, when IBI scores were noticeably lower than normal at the REF and MOD DIST reaches and about the same at HIGH DIST reaches. Accuracy of the IBI was lower in 2005 at 74 percent to two classes of biological integrity and 84 percent to three classes. As discussed in previous annual reports, 2005 was the second heaviest rainfall year on record since data began being kept in 1867. Unusually high peak stream flows during the winter of 2004-2005 scoured out local creeks and significantly altered the BMI communities inhabiting them, which had much lower density and diversity at the time of the 2005 surveys as compared to other years. The scouring flows were followed by a biological succession where quick colonizers including Baetidae mayflies and Chironomids were unusually dominant. Surveys were completed relatively early in 2005 (late April), which did not allow time for the BMI community to recover from this early state of biological succession. The accuracy of the IBI appears to have been impaired by this sequence of events. In future years with heavy rainfall and peak stream flows,

field surveys should be delayed until perhaps late May or June to allow more recovery of the BMI community, and hopefully more accurate IBI scores.

Sensitivity to Human Disturbance

ANOVA results indicate highly significant differences in IBI scores between the REF, MOD DIST, and HIGH DIST groups, with r^2 of 0.70 and $p < 0.0001$ (see Figure 4). All of the group means were significantly different from one another. The linear regression analyses showed highly significant positive relationships between IBI score and percent watershed undisturbed ($r^2 = 0.54$, $p < 0.0001$), habitat assessment score ($r^2 = 0.64$, $p < 0.0001$), and the composite of percent watershed undisturbed/habitat assessment score ($r^2 = 0.66$, $p < 0.0001$). The regressions are illustrated in Figures 5, 6, and 7. As indicated by the higher r^2 , there was a tighter fit (i.e., less variation) with the regression of IBI score vs. habitat assessment score compared to IBI score vs. percent of watershed undisturbed. This indicates that localized physical habitat conditions had a stronger link to biological integrity compared to watershed-level land use patterns. The regression of IBI score vs. the composite of percent watershed undisturbed/habitat assessment score and the ANOVA of IBI score amongst the study reach groups had the highest r^2 values. These results indicate that considering both watershed-level land use patterns and localized physical habitat conditions provided a better indication of the biological integrity of study streams.

V. Recommendations

The updated IBI is based on a set of streams that collectively represent a wide range of natural physiochemical variability and levels of human disturbance. In addition, significant fluctuations in rainfall and peak stream flows from year to year and their effects on the BMI communities of study area streams have been documented over the past 10 years. This has allowed for the development of an IBI that serves as a reliable tool for classifying the biological integrity of streams in the study area, monitoring their condition through time, and identifying any changes that may occur in the future from increased development, habitat restoration projects, and even long term climatic changes (e.g., global warming).

There are ways in which the collective data set could be diversified, for example by including streams in the study area that have not yet been surveyed, and expanding the study area further west and north to the Hollister and Bixby Ranch areas, Point Conception, Santa Ynez River watershed, etc. The IBI should be updated every 5 to 10 years to account for the greater range of conditions observed.

The updated IBI represents an excellent tool for assessing and monitoring the biological condition of freshwater streams in the study area. However, there is no equivalent tool for estuarine waters in the study area, which could be assessed using similar bioassessment methodology as used in this Program. IBIs have been produced for estuarine waters in many regions, and with adequate data one could likely be produced in the study area as well. Given the ecological importance of estuarine waters, and their importance as they relate to commercial and recreational uses and the local economy, the City and County should consider implementing an estuarine bioassessment program if funding allows.

Figure 4: ANOVA Comparison of IBI Score at REF, MOD DIST, and HIGH DIST Reaches

Means and distributions of IBI scores for study reach groups are represented. Top and bottom of diamonds are the 95 percent confidence limits, and the center lines are the means. The lower and upper lines are the 25 percent and 75 percent quantiles. N=190 (all study reaches), $p < 0.0001$, $r^2 = 0.70$. The p value is for the ANOVA where IBI score is the dependent variable and disturbance category is the independent variable.

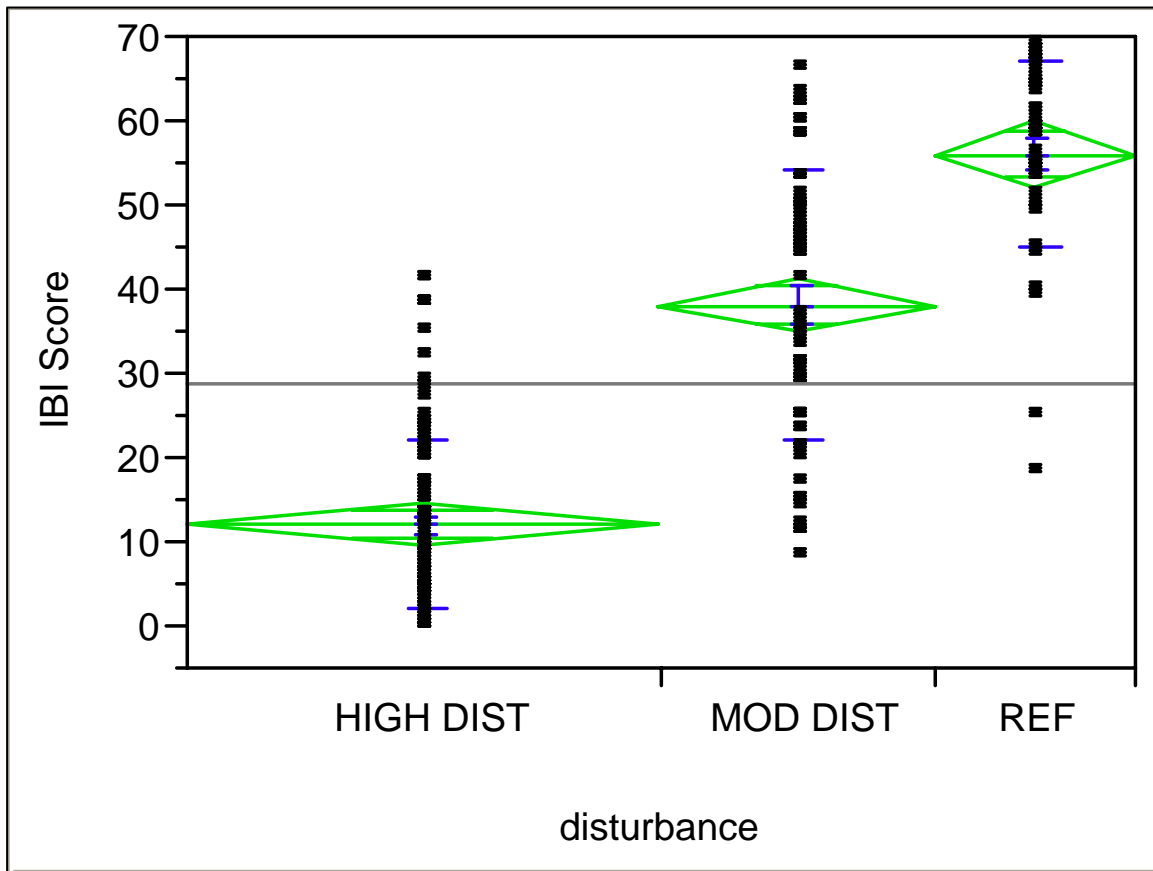


Figure 5: Linear Regression of IBI Score vs. Percent of Watershed Undisturbed

The graph shows the linear relationship between IBI score (dependent variable, y-axis) and percent of watershed undisturbed (independent variable, x-axis) amongst all of the study reaches (n=190). A significant positive relationship is indicated by the regression analysis ($p < 0.0001$, $r^2 = 0.54$). The best-fit line represents the relationship between the variables, the equation for which is:

$$\text{IBI Score} = -17.27667 + 0.6471196 \% \text{ undisturbed}$$

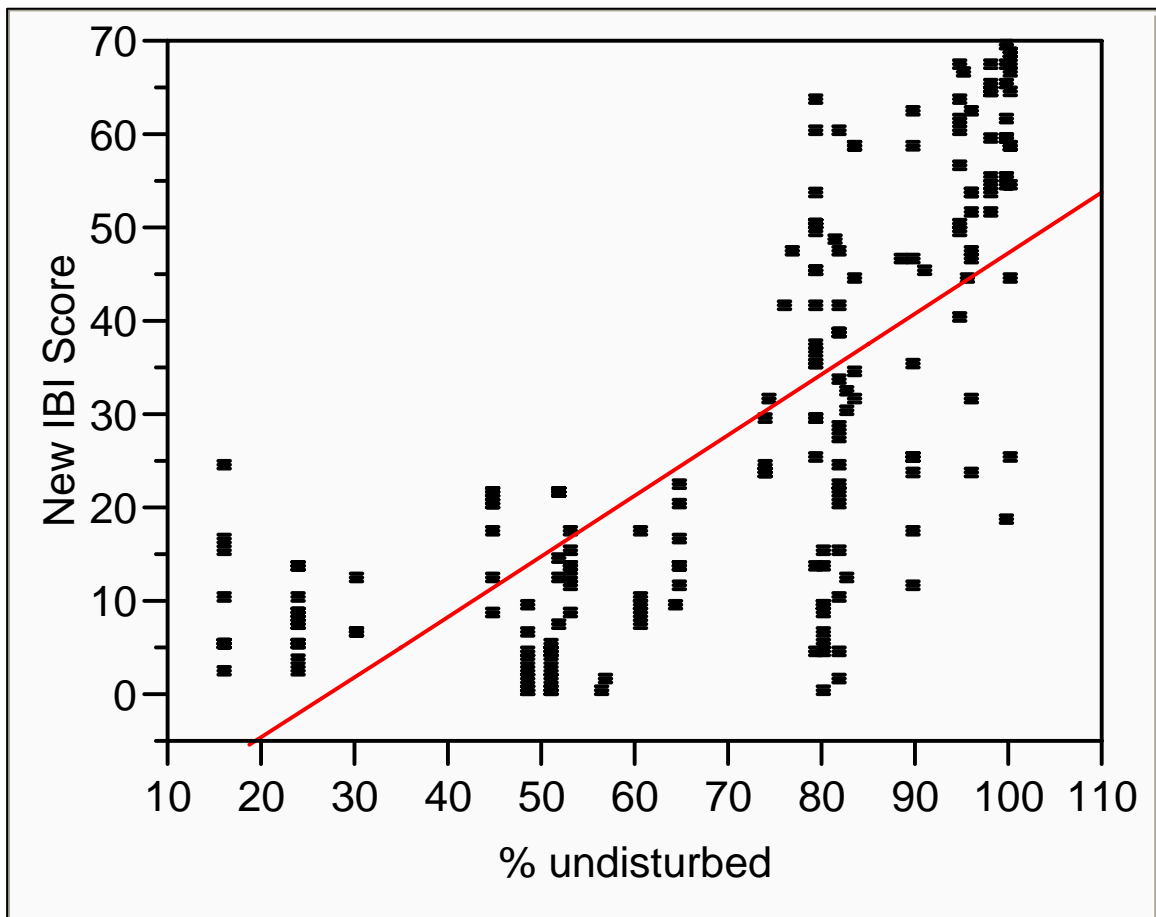


Figure 6: Linear Regression of IBI Score vs. Habitat Assessment Score

The graph shows the linear relationship between IBI score (dependent variable, y-axis) and habitat assessment score (independent variable, x-axis) amongst all of the study reaches (n=190). A significant positive relationship is indicated by the regression analysis ($p < 0.0001$, $r^2 = 0.64$). The best-fit line represents the relationship between the variables, the equation for which is:

$$\text{IBI Score} = -29.69897 + 0.4737229 \text{ Habitat Score}$$

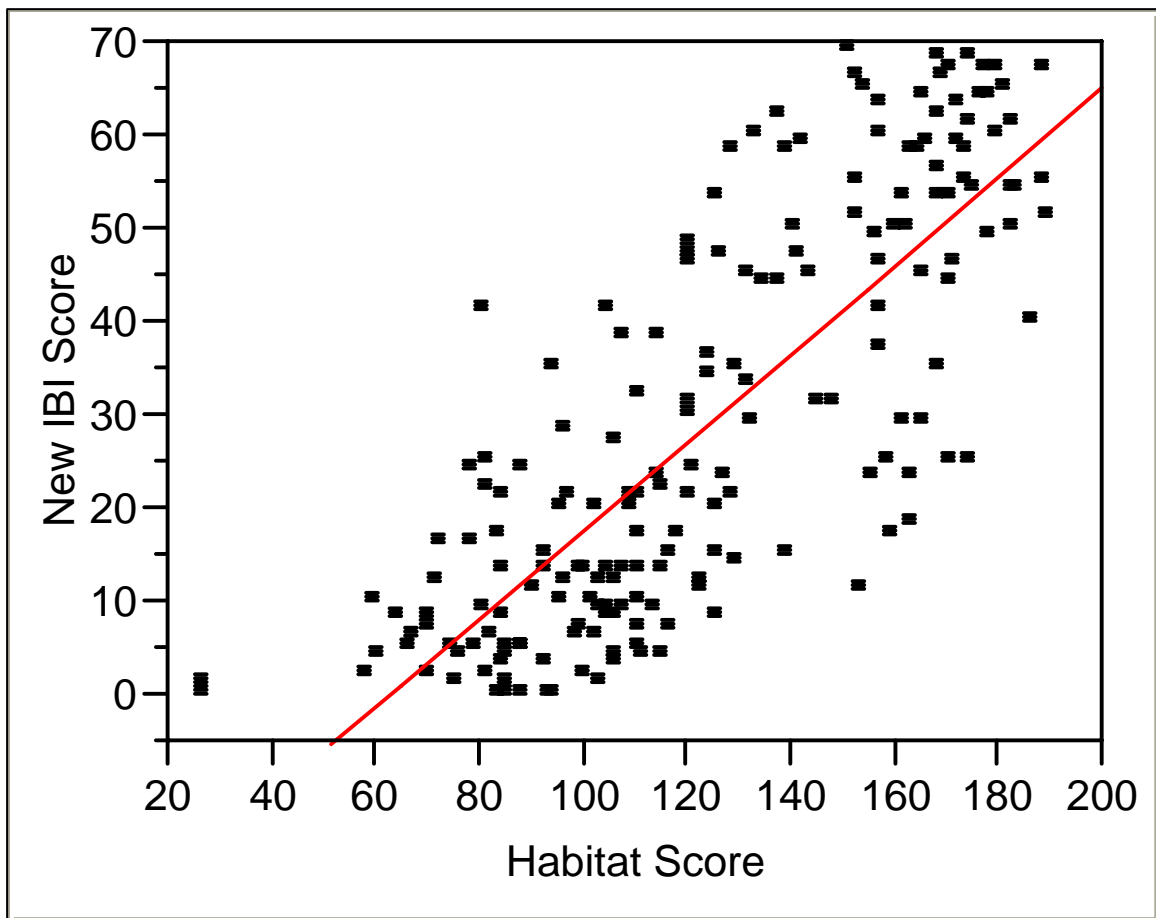
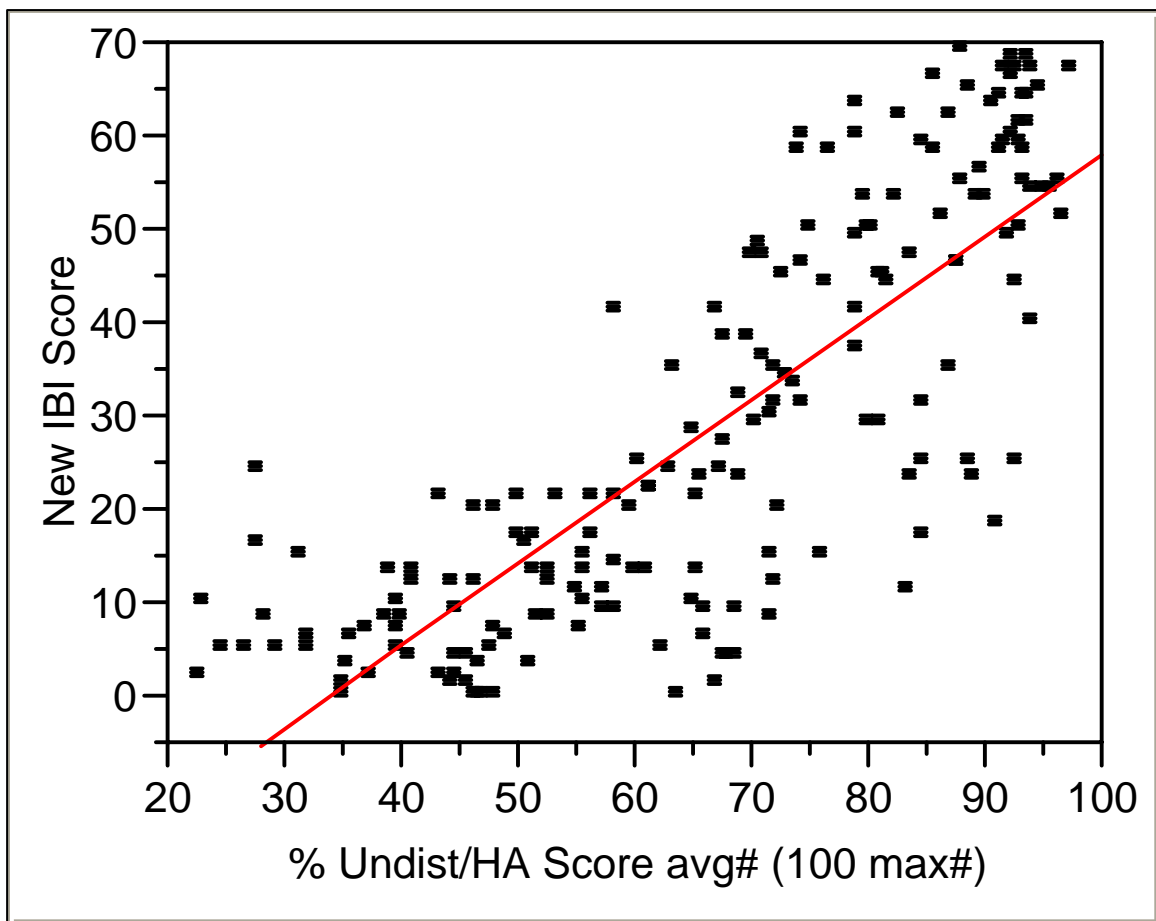


Figure 7: Linear Regression of IBI Score vs. Percent Watershed Undisturbed/Habitat Assessment Score Composite

The graph shows the linear relationship between IBI score (dependent variable, y-axis) and the percent watershed undisturbed/habitat assessment score composite (independent variable, x-axis) amongst all of the study reaches (n=190). A significant positive relationship is indicated by the regression analysis ($p < 0.0001$, $r^2 = 0.66$). The best-fit line represents the relationship between the variables, the equation for which is:

$$\text{IBI Score} = -29.70958 + 0.8800597 \text{ \% Undist/HA Score avg\# (100 max\#)}$$



VI. References

- Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Creeks and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition, EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water. Washington, D.C.
- Burt, W.H., and R.P. Grossenheider. 1976. A Field Guide to the Mammals, North America North of Mexico. Third Edition. Houghton Mifflin Company. Boston, New York.
- California Department of Fish and Game, Aquatic Bioassessment Laboratory. 2002. List of Californian Macroinvertebrate Taxa and Standard Taxonomic Effort. Revised April 30, 2002.
- Cooper, S.D., Dudley T.L., and N. Hemphill. 1986. The Biology of Chaparral Streams in Southern California. Proceedings of the Chaparral Ecosystems Research Conference, May 16-17, 1985, Santa Barbara, California. California Water Resources Center, University of California Santa Barbara. Report No. 62. June, 1986.
- County of Santa Barbara, Project Clean Water. 2002. Santa Barbara County Coastal Creeks Bioassessment Program, Annual Report, Year 2001.
- Dale, N. 1986. Flowering Plants, the Santa Monica Mountains, Coastal and Chaparral Regions of Southern California. Published by Capra Press in cooperation with the California Native Plant Society.
- ECORP Consulting, Inc. 2005. Results of 2004 Benthic Macroinvertebrate (BMI) Surveys Conducted for the City of Santa Barbara BMI Monitoring Program.
- Ecology Consultants, Inc. 2004. Santa Barbara County Creeks Bioassessment Program, 2003 Annual Report and Index of Biological Integrity.
- Hickman, J.C. 1993. The Jepson Manual, Higher Plants of California. University of California Press. Berkeley, CA.
- McAuley, M. 1996. Wildflowers of the Santa Monica Mountains. Second Edition. Canyon Publishing Company. Canoga Park, California.
- Merritt, R.W. and K.W. Cummins. 1996. An Introduction to the Aquatic Insects of North America, Third Edition. Kendall/Hunt Publishing Company.
- Moyle, P.B. 2002. Inland Fishes of California. University of California Press.
- Peterson, R.T. 1990. A Field Guide to Western Birds. Third Edition. Houghton Mifflin Company. Boston, New York.
- Stebbins, R.C. 1985. A Field Guide to Western Reptiles and Amphibians. Second Edition. Houghton Mifflin Company. Boston, New York.
- Stewart, B.P. and C.R. Nelson. 1994. Nymphs of North American Stonefly Genera (Plecoptera). University of North Texas Press. Denton, Texas.
- United States Geological Survey. Various dates. 7.5 minute quadrangle topographic maps.

APPENDIX A

DATA AND STATISTICAL ANALYSES SUMMARY

Insert data and statistical analyses

APPENDIX B

2009 CITY OF SANTA BARBARA CREEKS BIOASSESSMENT REPORT

2009 CITY OF SANTA BARBARA CREEKS BIOASSESSMENT REPORT

February 2010

Prepared for:
The City of Santa Barbara

Prepared by:



I. Introduction

This report provides analyses and discussions of the bioassessment data collected in 2009 at the 11 study reaches in the City of Santa Barbara, which are listed in Table 1, and shown in Figure 1.

Table 1 City of Santa Barbara Study Reaches		
Study Reach	Location	Latitude/Longitude Coordinates, Downstream End of Study Reach
SY1	Sycamore Creek just downstream of Mason Street bridge.	N34° 25.574' W119° 40.499'
SY3	Sycamore Creek along Sycamore Canyon Road approximately ¼-mile downstream of Highway 192 crossing and Coyote Creek/Sycamore Creek confluence.	N34° 26.413' W119° 40.553'
M1	Mission Creek just downstream of De la Guerra Street.	N34° 24.924' W119° 42.729'
M2	Old Mission Creek at Bohnet Park.	N34° 25.016' W119° 42.154'
M3	Mission Creek at upstream end of Rocky Nook Park.	N34° 26.653' W119° 42.539'
M4	Rattlesnake Creek (Mission Creek Tributary) approximately ½-mile upstream of Las Canoas Road crossing.	N34° 27.630' W119° 41.517'
M7	Old Mission Creek just downstream of Anapamu Street.	N34° 24.942' W119° 42.582'
AB1	Arroyo Burro just upstream of Alan Road.	N34° 24.605' W119° 44.485'
AB3	San Roque Creek (Arroyo Burro tributary) ¼-mile upstream of Foothill Road.	N34° 27.133' W119° 44.008'
AB5	Mesa Creek at Arroyo Burro estuary habitat restoration site, at the creek entrance to the estuary.	N34° 24.283' W119° 44.315'
AB6	Arroyo Burro just downstream of U.S. 101 crossing.	N34° 26.221' W119° 44.240'

Figure 1: City Study Reaches



II. Methods

See the main report (*Southern Coastal Santa Barbara Creeks Bioassessment Program, 2009 Report and Updated Index of Biological Integrity*) for a discussion of methodology.

III. Results

A. Physiochemical Data

Table 2 provides physiochemical data for the City study reaches collected this year, and ranges in values collected in this and previous years of study.

Study Reach	# years surveyed	Year	Wet stream width (ft.)	Habitat Assessment Score	Stream temp. (°F)	pH	Dissolved Oxygen (mg/l)	Conduct. (µS)	Specific conduct. (µS at 25°C)	% riparian canopy cover
SY1	7	Range	8.9-14.2	70-111	58.0-69.8	8.1-8.5	5.57-13.36	1786-2890	2158-3140	80-98
SY1		2009	11.0	70	65.5	8.4	10.50	2188	2489	98
SY3	4	Range	10.3-15.3	106-129	59.5-64.9	7.8-8.1	5.29-12.05	1632-1901	2004-2206	85-100
SY3		2009	15.0	106	64.2	8.1	10.25	1901	2206	85
M1	8	Range	13.1-21.8	80-106	60.4-80.4	7.7-8.3	9.57-15.86	1114-1252	1130-1445	27-71
M1		2009	16.5	106	60.4	7.7	10.61	1189	1445	49
M2	7	Range	8.3-9.8	64-115	63.3-72.3	7.5-8.4	4.05-10.52	1169-1350	1276-1423	8 to 73
M2		2009	9.8	115	66.9	7.9	9.76	1242	1390	73
M3	8	Range	12.7-15.9	156-170	50.5-66.6	7.7-8.8	6.77-10.45	702-984	887-1261	73-99
M3		2009	15.0	160	50.5	8.0	9.11	908	1261	97
M4	4	Range	13.2-18.5	142-183	54.0-68.4	8.0-8.5	8.74-9.32	626-810	791-926	98-99
M4		2009	18.5	142	54.0	8.5	9.28	700	926	98
M7	4	Range	6.5-13.0	92-106	60.2-63.9	7.7-7.9	6.76-8.84	1128-1226	1319-1449	83-94
M7		2009	13.0	100	60.2	7.9	8.84	1128	1364	94
AB1	8	Range	12.0-16.5	71-122	58.3-63.3	7.7-8.6	6.50-11.12	1350-1871	1608-2198	40-85
AB1		2009	16.5	116	58.3	7.7	6.50	1599	1997	85
AB3	9	Range	7.6-15.3	153-174	53.4-63.5	7.7-8.7	6.45-10.88	789-1618	960-2063	92-96
AB3		2009	15.0	153	60.3	8.0	10.06	1326	1613	93
AB5	3	Range	5.5-6.5	67-103	59.5-66.4	7.2-7.6	7.61-10.49	3260-3803	4002-4286	7 to 45
AB5		2009	6.5	103	59.5	7.2	7.61	3260	4002	45
AB6	1	Range	11.0	104	65.3	9.0	8.62	1003	1145	92
AB6		2009	11.0	104	65.3	9.0	8.62	1003	1145	92

B. Biological Data

Table B-1 provides a list of the plant species observed at the City study reaches. The table also indicates the number of native and introduced plant species observed at each study reach, and the percentage of plant species observed that are native. Plant observations from multiple years are combined in the table.

Table B-2 provides a list of vertebrate species observed at the City study reaches. Vertebrate species observations from multiple years are combined in the table. BMI data is provided in Table A-1 in Appendix A.

C. IBI Scores and Classifications

Table B-3 lists core metric values, IBI scores, and classifications of biological integrity for City of Santa Barbara study reaches in 2009. Table 3 provides IBI scores for this year's City study reaches, and the range of IBI scores and classifications of biological integrity in all years of study. Scores from the old IBI are provided also for comparison.

Study Reach	New/ Old IBI	IBI Score										Classification Range
		2000	2001	2002	2004	2005	2006	2007	2008	2009	Range	
SY1	New	-	-	21	20	17	21	20	12	8	8-21	Very Poor to Poor
	Old	-	-	18	24	36	38	22	22	24	18-38	Very Poor to Fair
SY3	New	-	-	-	-	-	21	21	14	12	12-21	Poor
	Old	-	-	-	-	-	38	22	26	30	22-38	Very Poor to Fair
M1	New	9	-	2	0	1	4	6	0	3	0-9	Very Poor to Poor
	Old	14	-	14	16	22	16	16	14	16	14-22	Very Poor
M2	New	-	-	8	5	7	5	10	13	13	5-13	Very Poor to Poor
	Old	-	-	14	16	30	26	18	18	24	14-30	Very Poor to Poor
M3	New	63	-	60	41	29	45	49	53	50	29-63	Poor to Excellent
	Old	50	-	48	46	40	50	38	50	46	38-50	Fair to Good
M4	New	64	-	-	-	-	-	64	54	59	54-64	Good to Excellent
	Old	52	-	-	-	-	-	56	48	54	48-56	Good to Excellent
M7	New	-	-	-	-	-	3	8	7	2	2-8	Very Poor
	Old	-	-	-	-	-	24	18	18	18	18-24	Very Poor to Poor
AB1	New	-	-	12	8	13	13	11	17	15	8-17	Very Poor to Poor
	Old	-	-	22	28	32	34	28	26	26	22-34	Very Poor to Poor
AB3	New	58	46	62	25	25	35	23	17	11	11-62	Poor to Excellent
	Old	44	44	44	-	38	44	20	30	20	20-44	Very Poor to Fair
AB5	New	-	-	-	-	-	-	6	6	12	6-12	Very Poor to Poor
	Old							22	14	20	14-22	Very Poor
AB6	New	-	-	-	-	-	-	-	-	9	9	Poor
	Old	-	-	-	-	-	-	-	-	18	18	Very Poor

- = study reach not surveyed in this year.

IV. Discussion

A. New vs. Old IBI Scores

Overall, scoring ranges and classifications of biological integrity are similar at the study reaches using either the new or the old IBI (see Table 3). There are some differences in classifications at particular sites, for example AB3 ranged from Very Poor to Fair with the old IBI in nine years of study, and from Poor to Excellent with the new IBI. However, there is no discernable pattern to the differences between the two IBIs, such as would exist if one IBI consistently produced a wider spread in scores compared to the other, or if one of the IBIs tended to score sites toward the higher or lower end of the range. The new IBI was developed using data from a greater number of study reaches that collectively represent a wider range of physiochemical conditions, and over a longer period of time with more diverse climatic trends and stream flow patterns. Given these facts, the new IBI is expected to provide improved accuracy in assessing the biological integrity of study streams into the future.

B. Overall Trends



The Santa Barbara coastal region and southern California as a whole experience highly variable rainfall and storm flow frequencies and intensities from year to year. Variable discharge patterns can have major effects on the stream biota. Extreme discharges such as what occurred in the winter of 2004-2005 can drastically alter streambed morphology, scouring out large volumes of stream bottom material and most of the aquatic life (e.g., algae, BMIs, fish, etc.) residing there. BMIs and other aquatic organisms must re-colonize the stream after peak flows subside, and the community is in a state of recovery for a period lasting up to several months or years. Early on BMI density and species richness (i.e., the number of species present) are relatively low, and early colonizers such as Baetidae mayflies are dominant. As the time between scouring events grows (i.e., in drought conditions), BMI density and species richness increase, and some of the slower colonizers such as Ostracods, Copepods, and Cladocerans (all non-insect taxa) may return and sometimes reproduce in great numbers, particularly in creeks with moderate to high levels of human disturbance.

Table 4 provides rainfall data from the Santa Barbara County Flood Control District stations in downtown Santa Barbara (elevation 100 feet) and San Marcos Pass (2,300 feet elevation), and peak daily discharge data from the USGS gauging station in Mission Creek at Rocky Nook Park by year for 2002, 2003, 2005, 2006, 2007, 2008, and 2009. While discharge varies from creek to creek, the gauging station data from Mission Creek shows similar patterns compared to other local stream gauges (e.g., Carpinteria Creek and San Jose Creek), and serves as a good example of the hydrology found in local creeks. Table 4 also provides averages of BMI density, and percent Baetidae from the six City study reaches (SY1, M1, M2, M3, AB1, and AB3) surveyed in all six of those years.

This past winter was relatively dry, with rainfall totaling 11.83 and 18.59 inches, respectively at the downtown Santa Barbara and San Marcos Pass stations. For comparison, average annual rainfall has been about 18 inches at the downtown Santa Barbara station where rainfall data has been collected since 1867, and 35 inches at the San Marcos station where rainfall data has been collected since 1965. Peak daily discharge did not exceed 16 cfs at the Mission Creek gauge this past winter, whereas peak daily discharge has regularly exceeded 100 cfs during relatively wet winters in the recent past, and was as high as 600 cfs as recently as 2005.

Table 4: Average Yearly Rainfall, Stream Discharge, and BMI Parameters					
Year	Prior Season Rainfall, Sept. 1 to April 30, Downtown Santa Barbara (inches)	Prior Season Rainfall, Sept. 1 to April 30, San Marcos Pass (inches)	Peak Daily Discharge, Mission Creek Gauge (cfs)	BMI Density (# per m ²)	% Baetidae
2002	8.84	14.28	5	1,950	5
2003	22.78	35.74	200	1,242	26
2005	36.25	70.02	600	199	49
2006	21.07	35.46	250	575	46
2007	6.41	10.84	5	749	16
2008	17.57	38.09	150	1,089	18
2009	11.83	18.59	16	632	22

BMI density was 632 individuals/m³ at the six study reaches, which is moderate in comparison with previous years. BMI density has typically been moderate to high following drier winters that lacked scouring flows. Baetidae mayflies have proven to be the most conspicuous colonizers in study creeks, and have typically been abundant following wet winters with heavy stream discharges. Baetidae comprised 22 percent of the samples this year, which is low to moderate compared to previous years, and consistent with the observed pattern of lower percent Baetidae following drier winters.

C. IBI Scores for Individual Study Reaches

The following discusses IBI scores (from the new IBI) at the individual study reaches.

Sycamore Creek Watershed

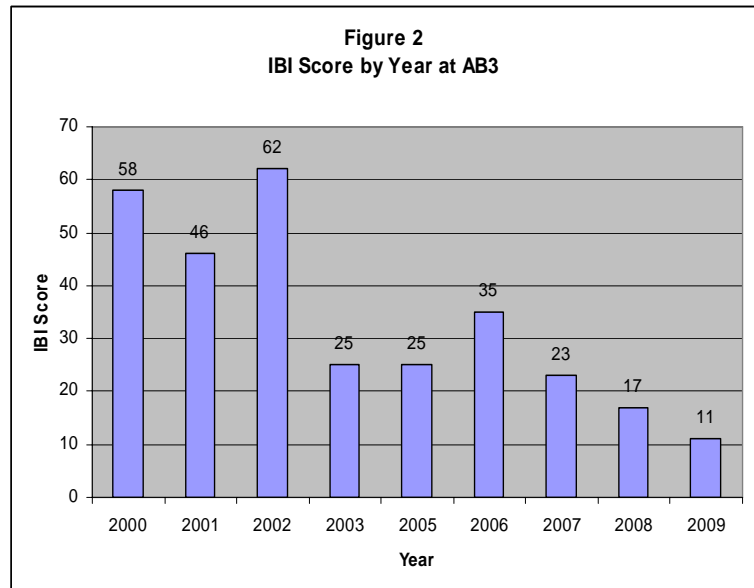
SY1 (downstream, highly impacted) and SY3 (upstream, moderately to highly impacted) both had lower habitat assessment scores this year compared to previous years, primarily due to noticeable increases in fine sediments and sand in the creek channel resulting from recent wildfires in the watershed. IBI scores were also lower than in previous years. SY3 remained in the Poor range, while SY1 dipped into the Very Poor range.

Mission Creek Watershed

Downstream, highly impacted study reaches M1, M2, and M7 continued to have low habitat assessment scores, impaired water quality, and low IBI scores in the Very Poor to Poor range. M2 (restoration site) had improved riparian canopy cover (73 percent) and habitat assessment score (115) due primarily to continued growth and development of the riparian corridor, which was initially planted in 2003. M3, a lightly disturbed site, and M4, a reference site, continued to have good water quality and IBI scores as in past years. The Good IBI classification at M4 came despite the noticeable impacts from recent wildfires in the form of increased fine sediments in the creek channel.

Arroyo Burro Watershed

Downstream, highly impacted study reach AB1 continued to have a fairly low habitat assessment score and Poor IBI classification. AB5, the restoration site on Mesa Creek, had increases in riparian canopy cover (45 percent) due to growth of recently planted riparian vegetation, and improved habitat assessment score (103). IBI score was Poor (13), but slightly improved from the two previous years. Conductivity was again very high at this study reach. AB6, a highly disturbed study reach located just downstream of the U.S. 101 crossing, was surveyed for the first time this year. This reach is downstream of the commercial area including La Cumbre Plaza and the car dealerships. This study reach had fairly low habitat assessment score of 104, high riparian canopy cover (92 percent), and appears to have moderately elevated conductivity, which may be a sign of water quality impairment. IBI score was 9, at the bottom of the Poor classification.



AB3 is by far the least disturbed study reach in this watershed based on physical habitat characteristics, upstream watershed land uses, and the limited water chemistry measurements that have been made. Habitat assessment score has consistently ranged from the 150s to 170s since 2000. These are among the best habitat assessment scores recorded at any of the study reaches studied in the Program. Correspondingly, IBI scores at AB3 were relatively high in the first few years of study, ranging from 46 to 62 (Fair to Excellent). However, IBI score at AB3 began to steadily decline in 2003, and dropped to a new low of 11 this year (see Table 3 and Figure 2). This most recent score is at the lower end of the Poor range. Steady declines in # insect families, # EPT families, % EPT minus Baetidae, % PT, and % sensitive BMIs have been evident, as has an increase in biotic index score. Given that there have been no major visible changes in habitat quality or in the limited water chemistry analyses, the substantial decline in IBI score at AB3 is puzzling. Similar declines have not been observed at similar stream reaches (e.g., M3, SA2, etc.) in the study area.

V. Recommendations

Continued study is needed to monitor the biological integrity of City streams, and help evaluate the ecological benefits of stream restoration efforts at sites such as M2 and AB5. Of concern is that there has been a substantial decline in the integrity of the BMI community at AB3 over the last several years, the cause of which is unknown at this time. A study should be developed and implemented to investigate the upstream watershed of San Roque Creek for causes of the decline in the BMI community. Such a study should include reconnaissance of the upstream

watershed to look for obvious clues such as illicit discharges of pesticides, fertilizers, septic tank effluent, or other pollutants, or increased fine sediments from poorly managed orchards. Bioassessment surveys and expanded water quality testing (e.g., nutrients, pesticides, bacteria, metals, etc.) could be conducted at two or three strategic locations based on information from the reconnaissance. However, such a study may need to be delayed, as the results could be confounded by impacts to water chemistry, sediment deposition, and riparian habitat from the recent Tea fire that burned much of the upstream watershed.